Far-Infrared Remote-Sensing Enabled by Room-Temperature Thermopile Imagers

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***Abstract*— This work presents a large-format thermopile focal plane module based on kilo-pixel arrays able to image from UV to far-infrared scenes. The spectral selectivity is achieved by means of butcher block filters integrated into sub-assembly modules as part of the optical telescope of the instrument.**

I. INTRODUCTION

THERMAL imaging is a remote-sensing technique capable of providing surface and atmospheric maps with high radiometric and spectral accuracy. Thermal imagers (TIs) based on thermopile technology are broadband, exhibiting a flat response over a wide spectral range (0.2-200µm), lightweight because no cryogenic cooler is required, and versatile as the detectors are insensitive to substrate temperature variations. This class of instruments has successfully flown on many missions such as Pioneer 10 & 11 (Infrared Radiometer), Voyager (IRIS instrument), Viking Orbiter (IRTM), Cassini (CIRS), Mars Reconnaissance Orbiter (MCS), and Lunar Reconnaissance Orbiter (Diviner) [1]. Thermopile pixels are inherently insensitive to instrument temperature drifts, and highly linear to incident radiation with overall detector sensitivity $D^* > 10^9$ cmHz$^{1/2}$/W @ 300K. The effort at JPL is to provide kilo-pixel arrays fully integrated with read-out integrated circuits (ROICs). Rigid-flex hybrid configurations are explored for plug-and-play focal plane module assemblies. Thermopiles are broadband, making them especially suitable for Earth and planetary missions.

II. THERMOCOUPLE OPTIMIZATION

Thermoelectric (TE) couples are fabricated using n-type (Bi-Te) and p-type (Sb-Te) alloyed materials. Several thermocouples are connected in series to increase the output voltage signal from the device. A series of high-temperature Bi-Te depositions highlighted a dramatic increase in performance of the n-type layer: 50% increase in Seebeck coefficient (uV/K) with a 3x drop in resistivity. Optimal deposition temperature appears to be in the 270-280C range similar to that of literature reports [2]. X-Ray diffraction analysis confirms single phase Bi_2Te_3 and high crystallinity while secondary electron microscopy and wavelength dispersive spectroscopy confirm homogenous Bi_2Te_3 films in the ideal 2Bi:3Te stoichiometry (*Figure 1*). One of the key factors to achieve a uniform targeted temperature profile during the TE deposition was to take advantage of a high thermal conductance sample stage as well as use high performance thermal paste to attach the substrate to the sample stage. High-temperature deposition on quartz substrates resulted into high-Seebeck coefficient and low resistivity Bi-Te compounds. The signal-to-noise-ratio (SNR) of thermopile detectors is limited by ZT of the TE materials that comprise the thermocouples and, to first-order approximation, is proportional to $ZT^{1/2}$. By applying these principles, the ZT of the materials alone could be improved by a factor of ~2×.

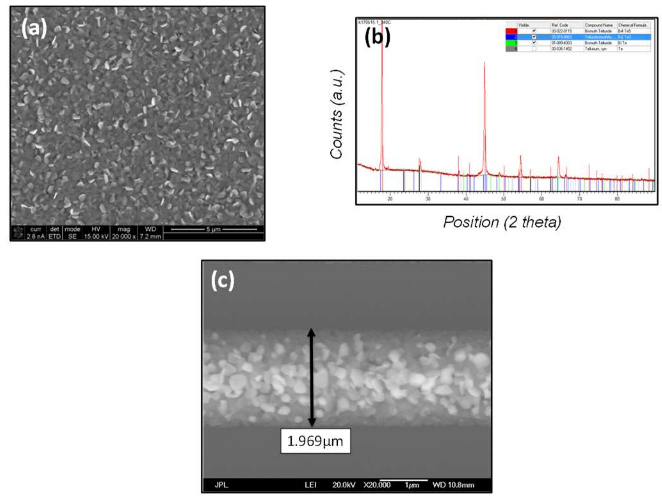

Figure 1: (a) TE deposition on unpatterned substrates. (b) X-Ray Diffraction (XRD) displaying crystalline nature/peaks of stoichiometric B-Te dense, textured films. (c) Patterned TE line which shows the peculiar thin-film platelet formation.

III. RESULTS

Kilo-pixel thermopile arrays based on Bi-Sb-Te ternaries are bulk micro-machined at the MicroDevices Laboratory at JPL. The pixels are arranged in a 64 (cross-track) x 16 (in-track) format.

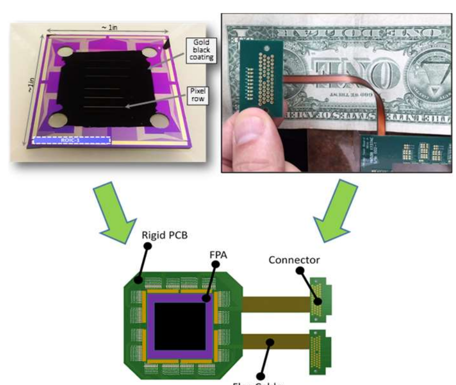

Figure 2: Micro-machined kilo-pixel array with gold black coating (left). Rigid-flex fabricated board prior to assembly (right). Cartoon representation of final assembly (bottom).

Pixel size, format, and array arrangement is application-driven and can be tailored depending on the science investigation. A gold black coating is deposited atop the array. Gold black is a porous nano-structured conducting film which acts as a broadband absorber from visible to far-infrared regions. *Figure 2* shows an image of a typical thermopile array (left). The image also displays a rigid-flex board (right) that can be used to integrate the detector at a higher level of assembly (bottom). *Figure 3* shows an annular-field three-mirror anastigmat telescope optical design to decouple in space filter assembly from detector array. This results into a much lighter, compact integrated system.

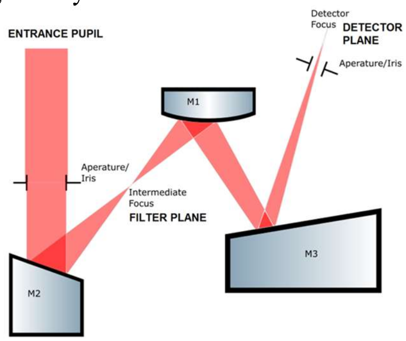

Figure 3: Three-mirror anastigmat (TMA) assembly as a compact telescope to separate in space filter from detector planes.

The objective of this work is to realize high-detectivity focal plane systems for far infrared detection at room temperature.

IV. Summary

Surface- and bulk-micromachining of thermopile detector arrays and incorporation into a fully-integrated focal plane module assembly is presented as remote-sensing thermal imager as potential payload in a variety of Earth and planetary missions. The TMA approach presented in this work constitutes a miniaturized telescope for far-IR focal-plane modules operating at room temperature.

V. acknowledgment

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References

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[2] Goncalves L.M et al., “Optimization of thermoelectric properties on Bi_2Te_3 thin films deposited by thermal co-evaporation”, Thin Solid Films 10, 2816-2821 2010.